High Efficiency, Ultra-Low-Emission Process Heater

Department of Energy
ITP Industrial Energy Systems Portfolio Review

Reston, VA

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TIAX
ExxonMobil Research and Engineering
Callidus Technologies
Norton Engineering

CALLIDUS TECHNOLOGIES, LLC

ExxonMobil Research and Engineering

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Topics to be covered include:

TIAX is leading a DOE project to develop an ultra-low-emissions, high efficiency, fired process heater.

- The development team includes ExxonMobil and Callidus Technologies.
- The project is being funded by DOE (50%) and the team (50%).
- Key technologies being developed include:
  - Ultra-low-emissions burner (< 10 ppm NO_x).
  - Advanced fired heater with 95% thermal efficiency based on lower heating value (LHV)
- The project will culminate in refinery heater retrofit demonstrations of key components.
- The burner technology has already been commercialized by Callidus.

Energy conservation and environmental compliance are key business objectives for the oil and chemicals industries.

- Existing fired heater technology is not cost effective for achieving high thermal efficiency at small to moderate duty.
  - About half of the fuel fired in process heaters in US refineries is impacted by this constraint.
- Emissions regulations for industrial facilities are tightening:
  - For example, the Texas State Implementation Plan calls for 75% overall NO_x reduction in the Houston-Galveston area, which has 29% of US refining capacity.
- Additional benefits of the integrated system include:
  - CO_2 emissions reduction
  - Avoided capital costs for alternative control technologies
  - Improved reliability
  - Increased process run lengths

Target applications are process heaters in refineries and chemical plants, which account for some 2000 TBtu/year - approximately 40% of US process heat energy consumption.

Refinery Processes

	Total Fuel Consumed TBtu/yr	Natural Gas Consumed TBtu/yr
Atmospheric distillation	351	104
Vacuum distillation	102	30
Catalytic cracking	156	46
Hydrocracking	50	15
Steam reforming	188	55
Hydrotreating	206	61
Catalytic reforming	208	61
Thermal cracking	9	3
Delayed coking	103	30
TOTAL	**1373**	**405**

Chemicals Processes

	Total Fuel Consumed TBtu/yr	Natural Gas Consumed TBtu/yr	Fraction Natural Gas %
Ethylene	342	110	32
Ammonia	189	189	100
Carbon Black	40	38	95
Methanol	28	28	100
P-Xylene	25	23	90
Vinyl Chloride	17	17	100
Urea	16	16	100
Styrene	17	13	78
Benzene	9	8	90
TOTAL	**683**	**442**	**65**

Source: Gas Research Institute Report GRI-96/0353

We have assembled a strong team to develop and commercialize the advanced process heater technologies.

TIAX

- Prime contractor and DOE interface
- Combustion expertise
- Pilot scale component testing
- Computational fluid dynamic modeling

ExxonMobil Research and Engineering

- Process heater expertise
- Process sensing and control expertise
- Commercial system integration/ testing
- Field demonstration planning/execution
- Process heater commercialization

Callidus Technologies

- Burner expertise
- Commercial burner development
- Commercial scale testing
- Burner system commercialization

Norton Engineering (EMRE sub)

- Process heater design expertise
- Control system expertise
- Heat transfer expertise
- Process heater cost estimation

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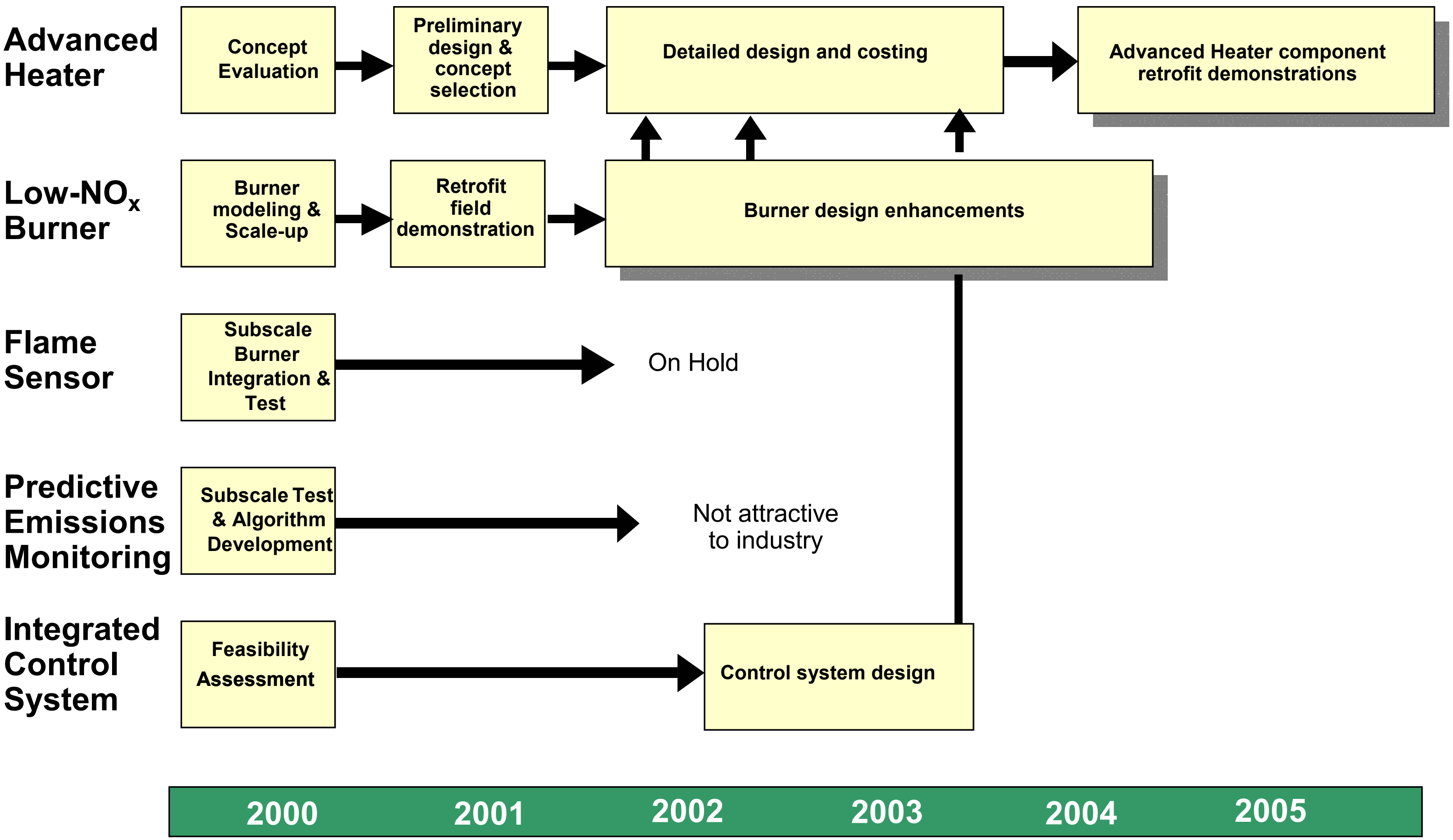
Advanced Process Heater Overview Project Structure & Overall Schedule



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Goal: To develop designs and components for an integrated process heating system that improves efficiency and reduces NO_x emissions.

Challenges: Current combustion air preheating systems are too expensive to be installed on most fired process heaters. The use of preheated air increases emissions of NO_x. Maintaining stable burner operation while achieving ultra-low NO_x emission is difficult.

Benefits: Reduced NO_x ,CO_2 emissions and improved efficiency for refineries and chemical plants.

FY05 Activities: Demonstrate key components (IR imaging, radiant tube enhancements) retrofitted to a refinery fired heater.

Participants:
- TIAX
- ExxonMobil
- Callidus Technologies
- Norton Engineering

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Barriers

- Cost of air preheating systems
- Impact of air preheating on NO_x emissions
- Achieving stability and ultra-low NO_x in natural draft burners over a wide range of fuel gas compositions

Pathways

- An integrated system is being developed, incorporating:
  - Ultra-low emission burners developed through CFD modeling
  - Modular, integrated heater design optimized for the burners
- To capture near-term benefits, system components are being designed for use in retrofit applications.

Critical Metrics

- Fired heater thermal efficiency > 95% (LHV)
- NO_x emissions < 10 ppm
- Return on investment meeting industry standards

Benefits	2020 [1]
Energy savings	84 trillion Btu
NO_x reduction	150,000 tons
Carbon reduction	1.3 MTCe
Cost savings	$1.5 billion

1. Proposal estimates, updated 10/03 by Energetics

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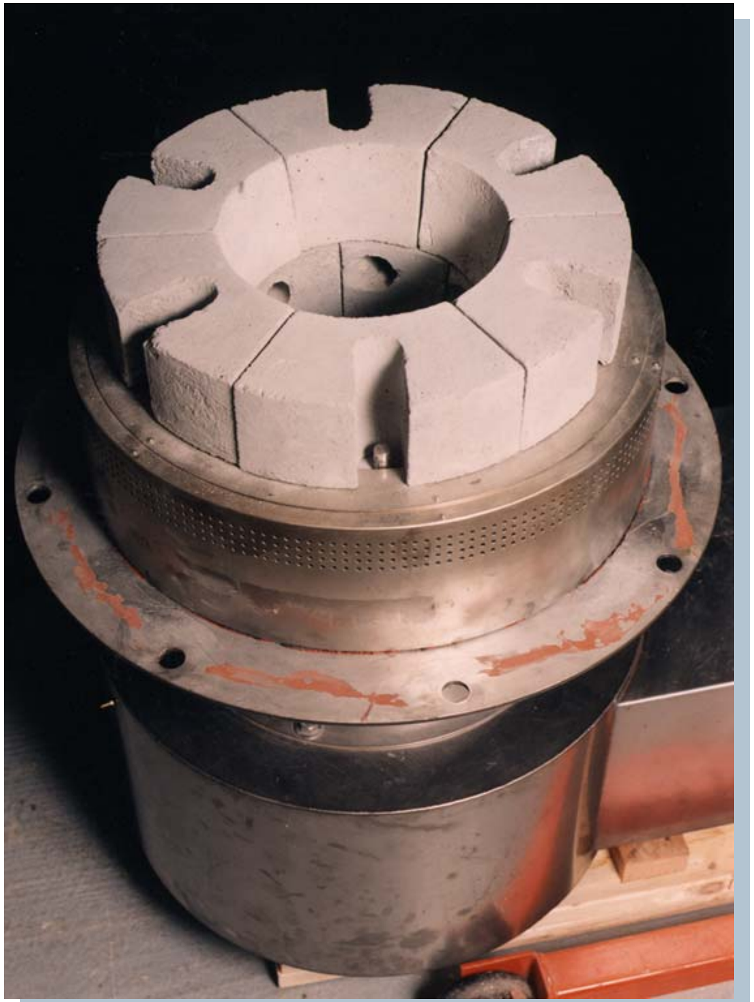
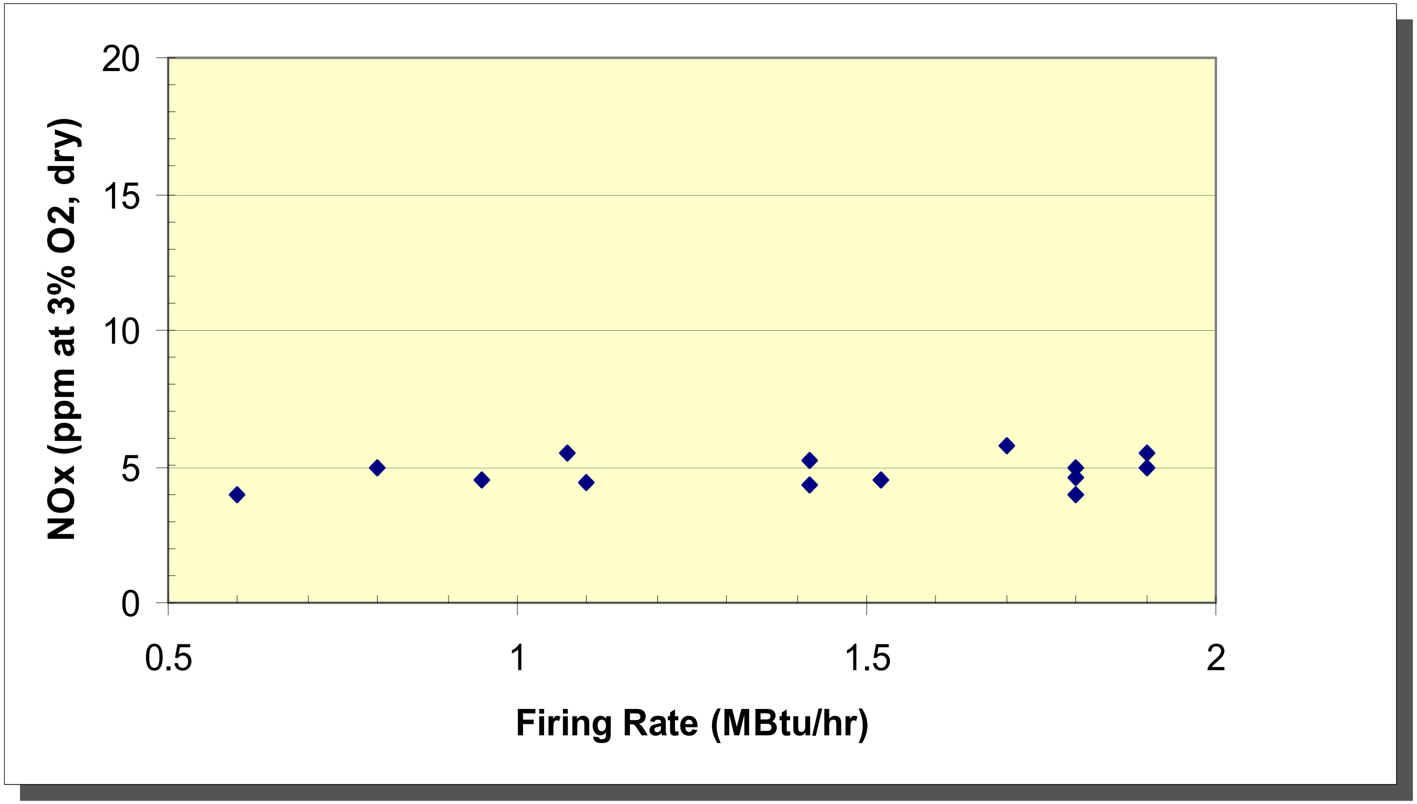
A flexible 2 MBtu/hr prototype was designed and built by TIAX.

- The prototype design was optimized through chemical kinetics and computational fluid dynamics (CFD) modeling.
- The burner was tested in both TIAX's Industrial Test Furnace and Sandia's Burner Engineering Research Lab.
- This Initial work was funded by the Gas Research Institute.

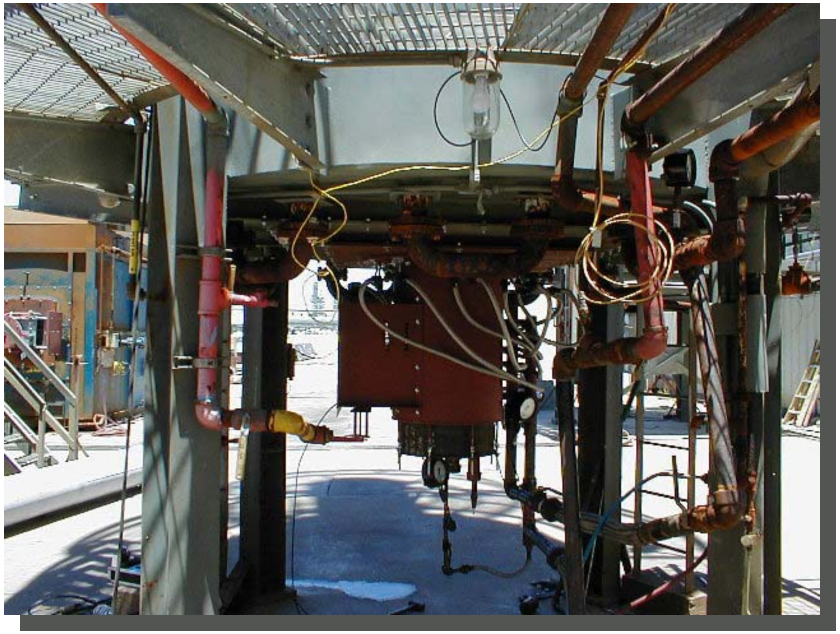


A comprehensive parametric assessment of the effect of burner design parameters on flame stability and emissions was conducted.



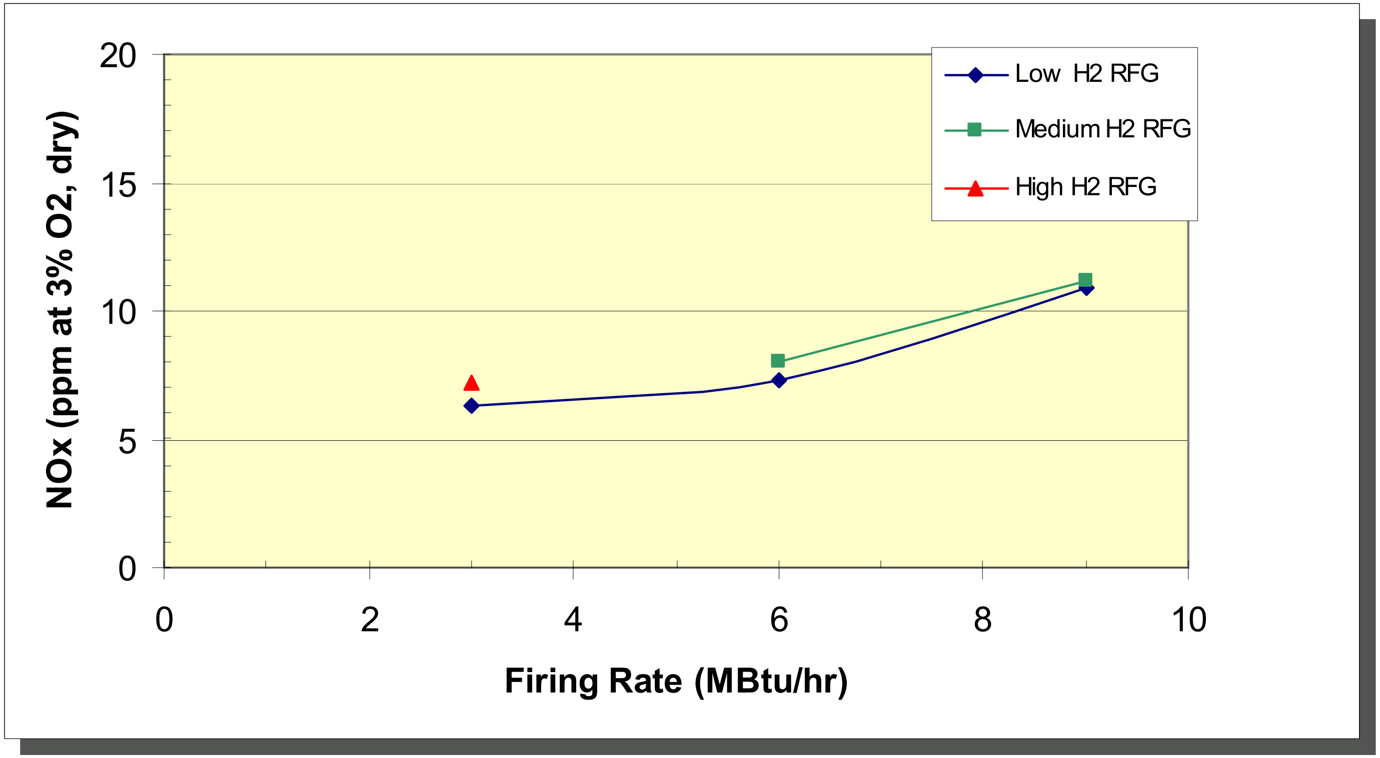
Scale-up of the burner to 9 MBtu/hr was successfully completed at Callidus' test facility.

- In-flame data from Burner Engineering Laboratory were used to develop a reacting flow CFD model of the burner.
- The CFD model was used to develop design options for the full-scale burner.
- A detailed mechanical design for the full-scale burner was developed.
- A prototype full-size burner was built and tested at Callidus.
- The technology was patented by Callidus.



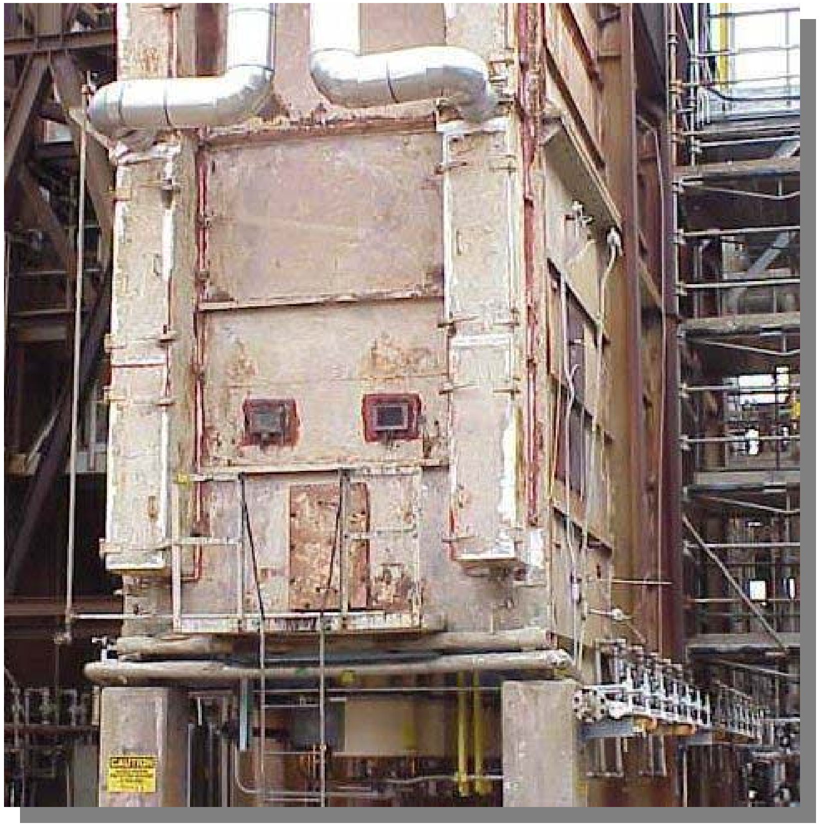
- Primary fuel jets are optimized to entrain flue gas and mix prior to ignition.
- Secondary fuel jets are optimized for entrainment, stability and NOx control.
- A robust flame stabilizer is incorporated.

NO_x emissions of 7-11 ppm were achieved for a wide range of fuel gas compositions in Callidus' test furnace.



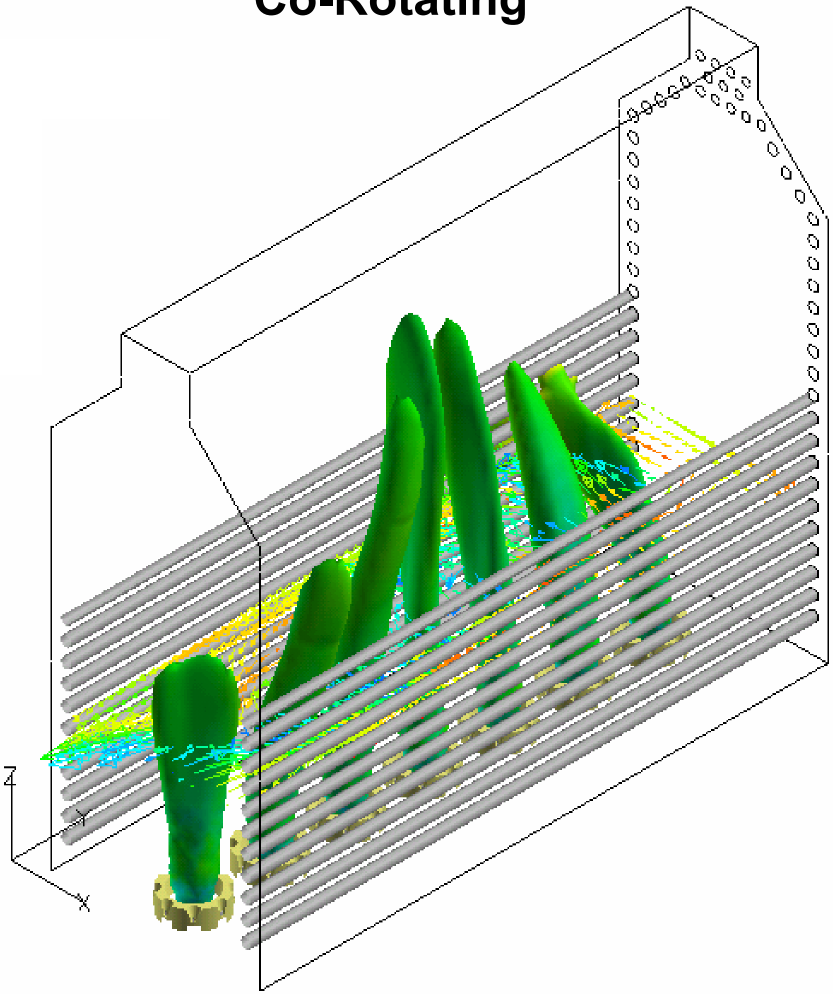
A refinery process heater was retrofitted with the project's burner technology.

- An atmospheric pipestill furnace at an ExxonMobil refinery was selected to demonstrate the project's burner technology.
  - Horizontal tube cabin configuration
  - 125 MBtu/hr higher heating value (HHV) maximum firing rate
  - Fuel gas composition varied from high methane to high hydrogen
- A computational fluid dynamics model was utilized to predict radiant section performance and thereby identify potential problems.
  - Flue gas flow patterns
  - Flame geometry



Burner Demonstration CFD Modeling

Co-Rotating



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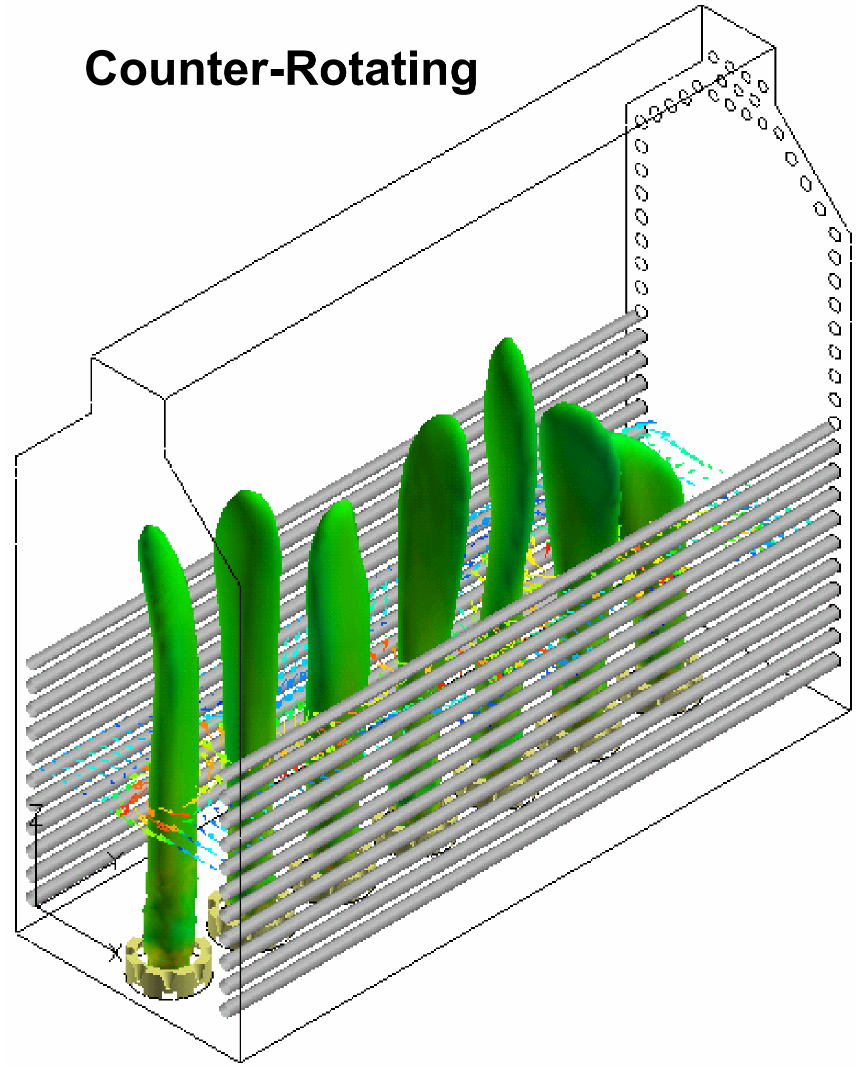

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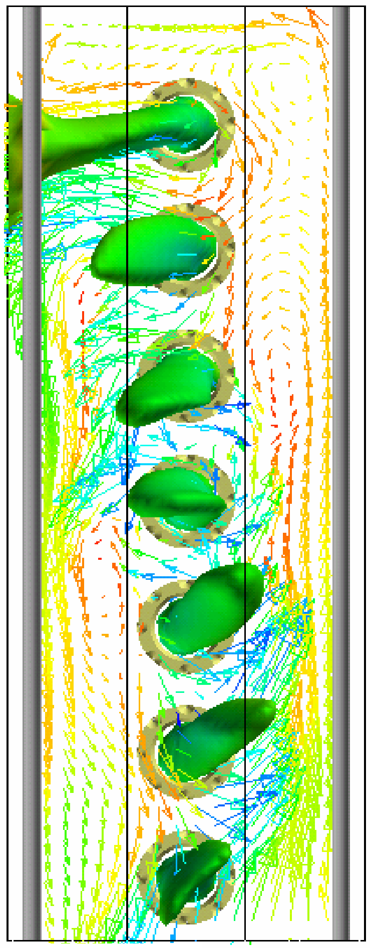

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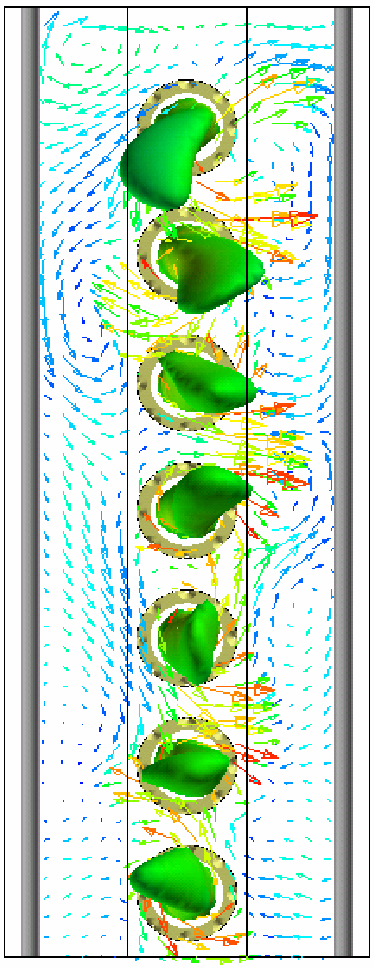

Burner Demonstration Retrofitted Burners in Operation

The demonstration process heater was successfully operated.

- A set of 14 field test burners were manufactured by Callidus for the retrofit demonstration. The fired heater was started-up in May 2001.
  - Flame geometry and flue gas flow patterns were consistent with the CFD predictions.
  - Heat flux profile met specifications.
  - Burner stability was good when fuel composition was within specifications; however, pulsations were experienced when methane content exceeded 85%.
- Temporary gas tips were designed and installed in July 2001 to eliminate pulsation with high methane fuels.
- A new flame stabilizer and gas tips were developed to enhance flame stability and lower NO_x. These were retrofitted in December 2002.
  - No stability problems.
  - NO_x averaged about 0.025 Lb/MBtu HHV (22 vppm).
- The new flame holder design is now standard for other CUB installations.

Callidus has sold over 1400 CUB burners to many oil and chemical companies.

- Heater types include: horizontal cabin, vertical box, and vertical-cylindrical.
- Burner Types include: natural draft, forced draft, low-Btu gas with and without preheated combustion air.
- Emissions of NO_x range from 5 to 30 ppm.
  - Furnace geometry and burner layout impact NO_x level.
  - Increased burner-tube and burner-burner spacing favors lower NO_x levels by improving recirculation patterns in furnace.
- Callidus' field experience in these furnaces has guided the Advance Heater design.
  - Low flue gas temperature at floor is expected to favor lower NO_x levels.

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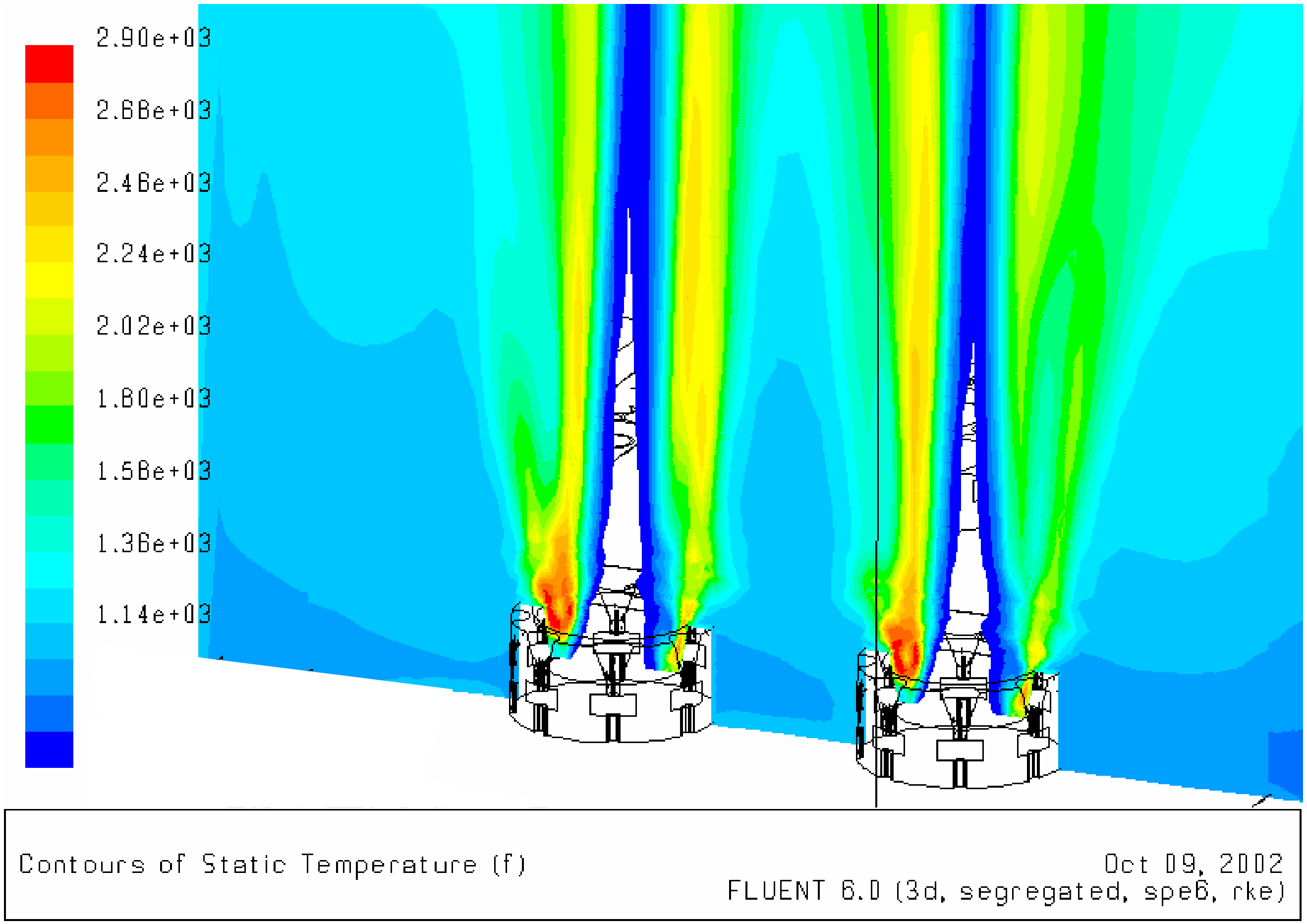
Design options for the advanced heater configuration were evaluated and a detailed design was completed.

- Several fired heater arrangements that can achieve 95% efficiency (LHV basis) were evaluated from constructibility and cost aspects.
- Several new and existing compact heat exchanger technologies were evaluated as combustion air preheater candidates.
- Promising technologies for enhancing radiant and convection heat transfer were identified and evaluated with CFD models.
- A final arrangement was selected.
- A detailed design was completed for a 100 MBtu/hr heat-to-oil vacuum pipestill furnace.
- Total erected cost for the Advance Heater was estimated.

Design integration of the CUB burners with the advanced heater was accomplished through CFD modeling.



An economically attractive heater that achieves high efficiency and low emissions was developed through the novel integration of commercial and newly developed components.

- Newly developed components:
  - Ultra-low-NO_x burners
  - Infrared (IR) imaging system for tube metal temperature monitoring
  - Enhanced heat transfer for radiant section tubes
  - Enhanced heat transfer for convection section tubes
- Key commercially available technologies:
  - Compact air preheater
- Key integration areas:
  - Burner with radiant section geometry
  - Convection section with radiant section and air preheater
  - Flue gas and air ducting with air preheater
  - Structural support
  - Modular design

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Several technology demonstrations are included in the DOE project to validate key Advanced Process Heater components.

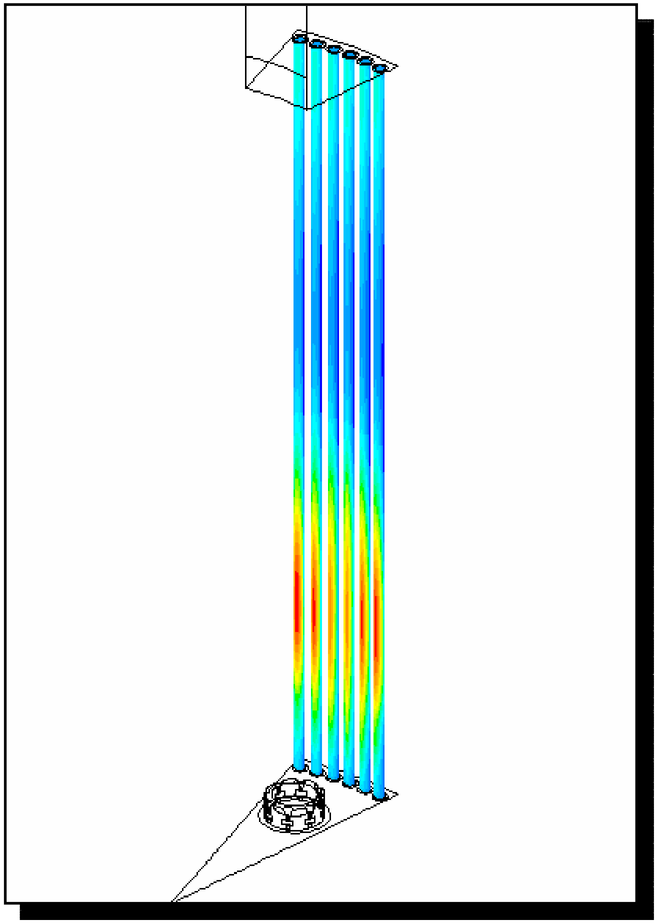
- Callidus Ultra-Blue (CUB) burner
  - Completed
- Improved CUB burner
  - Demonstration planned at Callidus in 4Q04
- Radiant tubes with enhanced heat transfer
  - Demonstration in retrofit refinery heater radiant section planned in 2005
- Tube metal temperature monitoring with low-cost IR imaging
  - Monitoring in a refinery heater is ongoing in 2004 and continues in 2005

A new tile configuration has been developed to improve performance of the CUB burner.

- Improved stabilization mechanism and increased mixing rate of flue gas with combustion air could yield:
  - Lower NOx
  - Shorter flame
  - Smaller tile diameter
- Prototype tile is being manufactured by Callidus.
- Testing at Callidus is scheduled for October 2004.

Enhancing heat transfer to radiant tubes can improve process heater performance.

- Reduced peak heat flux levels can provide:
  - longer run length, due to reduced coking rate
  - longer tube life, due to reduced metal temperature
  - increased production rate
- Reduced flue gas temperature at floor of heater can lower NOx emissions from ultra-low emission burners.
- The demonstration is not likely to start until late 2005.



Development of Advanced Tube Metal Temperature Monitoring can increase reliability and improve performance.

- Currently, Tube Metal Temperature (TMT) monitoring on fired heaters typically consists of:
  - Thermocouples welded to a few tubes at selected locations, providing continuous data for monitoring and alarming
  - Periodic broader surveys of TMTs via portable IR imaging cameras through available observation doors in firebox
- Reliability and operational credits can be realized through continuous monitoring of TMT at more tube locations.
  - Adding more welded TMT thermocouples is too expensive
  - Mutiple, permanent IR imaging cameras undemonstrated and, in past, thought to be too expensive
- Recently a low cost IR camera was identified.
  - A hand-held camera has been commercialized but further development is needed for permanent installation on a fired heater
- Initial screening demonstration was completed in 2004. The retrofit demonstration is planned for 2005.

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The Advanced Heater design provides economic and emissions incentives relative to conventional fired heater technology.

Fired Heater Type	Efficiency (%, LHV)	Heat Fired (MBtu/hr, LHV/HHV)	Total Erected Cost (normalized)	NOx Emissions (Tons/yr)	CO_2 Emissions (kTons/yr)
Conventional	83	120/132	100	11.5	73
Conventional with Air Preheater	90	111/122	146	16	67.5
Advanced with Air Preheater	95	105/115	148	7.5	63.5

- The Advanced Process Heater's return on incremental investment (based only on fuel cost savings) meets typical industry requirement at a fuel cost of about $3.50/MBtu.
- NO_x and CO_2 credits can increase the economic attractiveness of the Advanced Process Heater.